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The effect of UV treatment on highly polluted and normal operated swimming pools

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Polluted swimming pools and UV treatment

"*It should be light blue, transparent*" (Mario Andrada, speakerman, Olympic Games, Rio, 2016) was the comment for the "green lake". Swimming pools are sensitive recirculating systems. A malfunction in water treatment units or a poor operating decision could possibly lead to health-endangering or aesthetically unacceptable conditions for swimmers, with a lengthy and expensive remediation.

Chlorine is efficient in killing pathogens and thus it is used in virtually all public pools. Chlorine also oxidizes organic matter and as forms disinfection by-product (DBP) such as lung and irritant chloramines and organochlorine compounds like trihalomethanes (THM) which are suspected to be genotoxic.

Medium pressure (MP) ultraviolet (UV) lamp treatment may be used to reduce chloramine concentrations, but at the risk of increased chlorine consumption and THM formation in some pools while other pools experience no increases. Several studies have investigated the effects of UV on DBP formation in normal operated pools with relatively good water quality (Beyer et al., 2004; Cassan et al., 2011, 2006; Kristensen et al., 2009; Cimetiere and De Laat, 2014; Spiliotopoulou et al, 2015).

We compared the effect of UV treatment on chlorine consumption and trihalomethane formation in a typical pool and a highly polluted pool due to an extreme bather load. A pool with high bather loading might contain higher concentration of total organic carbon (TOC) and nitrate.

Higher TOC means more organic matter could be altered to more chlorine reactive products by primary photochemical reactions in the UV treatment. Nitrate is known to absorb UV-light and produce hydroxyl radicals which might degrade organic matter to more chlorine reactive compounds in secondary photochemical reactions.

The aim of the study was to investigate the impact of poor water quality on DBP formation in UV treated pools due to increased TOC or increased nitrate concentration. The DBPs and more specific the total THM (TTHM), were measured after post-UV chlorination and were compared to a non-UV irradiated chlorinated sample.

The 2016 Olympic dive pool turned green by alga after accidental dechlorination caused by addition of H_2O_2.

Water samples

Pool water were collected during regular operating hours from two public swimming pools (Denmark) with highly varying bathing load. The normal operated pool was used for leisure, with few scheduled activities per week. The second pool was a training and rehabilitating pool with high bathing load (scheduled courses every 30 min). TOC, nitrate, pH, free and combined chlorine measured immediately by standard methods.

Table 1. Initial pH, TOC, NO_3^- and NO_2^- concentration (mg/L) analysis for the two pools.

Swimming pools	pH	TOC	Natural NO_3^--N	NO_2^--N after UV/NO_3^-
Normal pool	7.0	1.6	4.2	0.55
Polluted pool	7.2	7.0	1.6	0.80

UV treatment

Water samples were spiked by a radical initiator (Cl_2 or NO_3^-) and then were subjected to irradiation. UV treatment was performed in a quasi-collimated beam apparatus with a doped medium pressure lamp (Fig. 1). The UV dosage was equivalent to UV treatment of full-scale and calculated as in Hansen et al. (2013).

The Cl_2 dosage was based on Cl_2 consumption to achieve a residual Cl_2 after 24h at approx. 1 and 31 mg Cl_2 /L.

The total Cl_2 consumption in laboratory experiments were determined by ABTS (Pinkernell et al., 2000) and TTHMs were quantified by GC-MS (Hansen et al., 2012).

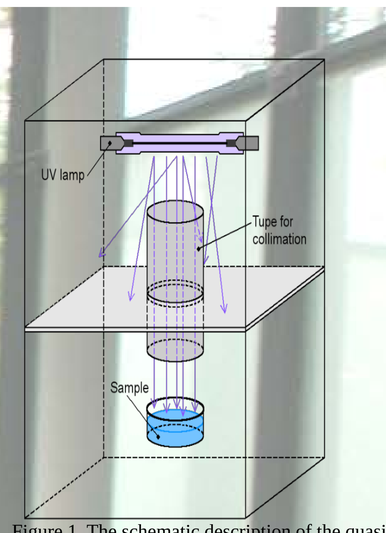

Figure 1. The schematic description of the quasi-collimated beam irradiation apparatus.

Which is the effect of increased TOC and nitrate on DBP formation?

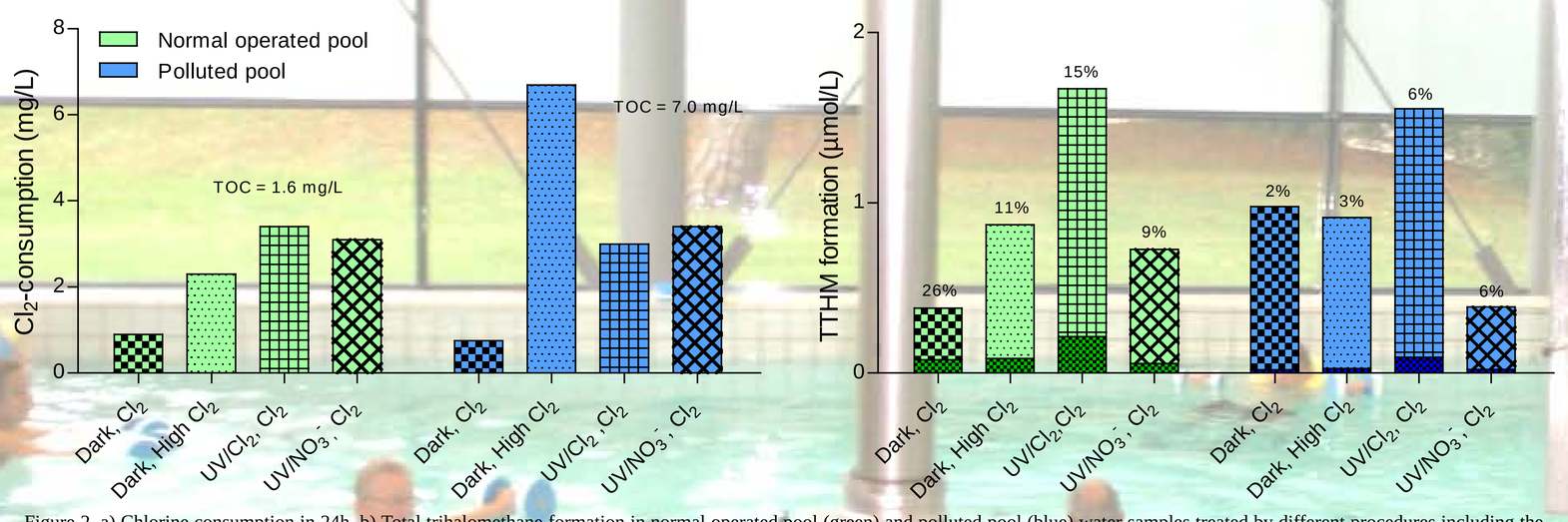

Figure 2. a) Chlorine consumption in 24h. b) Total trihalomethane formation in normal operated pool (green) and polluted pool (blue) water samples treated by different procedures including the brominated species (dotted part of the bar graphs). The percentages represent the incorporation of brominated fraction in the TTHM. Dark, Cl_2 = non irradiated chlorinated sample; Dark, High Cl_2 = non irradiated high dose chlorinated sample; UV/Cl_2,Cl_2 = post-UV chlorinated sample; UV/ NO_3^-,Cl_2 = nitrate addition in post-UV chlorinated sample.

Effect of UV on pool water

- UV treatment as well as increased chlorine dosing (simulating extended exposure time) increase chlorine consumption.
- UV treatments as well as increased chlorine dosing increase TTHM formation.

Thus, confirming our previous results, UV-treatment appears to accelerate reactions between organic matter and chlorine through making the organic matter more reactive to the chlorine it meets in the pool after the treatment..

High nitrate concentration

- High nitrate concentrations inhibited the increase in TTHM formation caused by UV-treatment.
- High nitrate doesn't change the increase of chlorine consumption induced by UV treatment.

This indicates that hydroxyl radical formation from nitrate photolysis are unimportant and the shielding of organic matter from UV by nitrates strong UV absorbance dominates the TTHM formation.

The similar induction of chlorine consumption by UV is explained by the nitrite formed which consumes chlorine.

High organic matter concentration

- Chlorine consumption was unaffected by TOC with or without UV treatment.
- Only with increased chlorine dosing (simulating extended exposure time) did chlorine consumption increase reflecting more organic matter to be oxidized.
- TTHM formation didn't increase more with UV in the high TOC water.

This suggests that all photons cause activation of organic matter rate than the light field causing a constant fraction of the organic matter to become chlorine consuming and form TTHM precursors.

Initial conditions

- **TOC:** The TOC of the polluted pool was 4-fold higher that what is usually found in a normal operated pool (Table 1).
- **Initial NO_3^- - N:** Initial nitrate concentration for both pools was bellow the threshold value (10 mg-N/L; Lyon et al., 2012) (Table 1).
- **NO_2^- -N after UV:** Nitrate was spiked to the samples to achieve a concentration of 11.1 mg NO_3^--N/L. After UV exposure, the reaction product nitrite, NO_2^-, was determined (Table 1).

Discussion and Conclusions

- Conversely to our expectations, the high TOC does not contribute notably neither in chlorine consumption nor in DBP formation in post-UV chlorination treatment.
  - Results suggested that there might be a saturation in UV ability to penetrate the water inhibiting the further removal of DBPs.
  - Possibly repeated post-UV chlorination treatment would have a different effect on DBP removal.
- NO_3^- spiked UV treated samples stimulated the least TTHM.
  - NO_3^- strongly absorbs UV light and apparently this results in shielding the water surface from the UV light and therefore, further reactions are inhibited.